M get larger, the cost of making such a crossbar switching network becomes prohibitively expensive.

The number of switches of input stage 110 and of output stage 120 can be denoted in general with the variable r for each stage. The number of middle switches is denoted by m. The size of each input switch IS1-IS4 can be denoted in general with the notation $n*m$ and of each output switch OS1-OS4 can be denoted in general with the notation $m*n$. Likewise, the size of each middle switch MS1-MS8 can be denoted as $r*r$. A switch as used herein can be either a crossbar switch, or a network of switches each of which in turn may be a crossbar switch or a network of switches. A three-stage network can be represented with the notation $V(m,n,r)$, where n represents the number of inlet links to each input switch (for example the links IL1-IL3 for the input switch IS1) and m represents the number of middle switches MS1-MS8. Although it is not necessary that there be the same number of inlet links IL1-IL12 as there are outlet links OL1-OL12, in a symmetrical network they are the same. Each of the m middle switches MS1-MS8 are connected to each of the r input switches through r links (hereinafter "first internal" links, for example the links FL1-FL4 connected to the middle switch MS1 from each of the input switch IS1-IS4), and connected to each of the output switches through r second internal links (hereinafter "second internal" links, for example the links SL1-SL4 connected from the middle switch MS1 to each of the output switch OS1-OS4).

Each of the first internal links FL1-FL32 and second internal links SL1-SL32 are either available for use by a new connection or not available if currently used by an existing connection. The input switches IS1-IS4 are also referred to as the network input ports. The input stage 110 is often referred to as the first stage. The output switches OS1-OS4 are also referred to as the network output ports. The output stage 120 is often referred to as the last stage. In a three-stage network, the second stage 130 is referred to as the middle stage. The middle stage switches MS1-MS8 are referred to as middle switches or middle ports.

In one embodiment, the network also includes a controller coupled with each of the input stage 110, output stage 120 and middle stage 130 to form connections between an inlet link IL1-IL12 and an arbitrary number of outlet links OL1-OL12. In this

embodiment the controller maintains in memory a pair of lists of available destinations for the connection through a pair of middle switches (e.g. MS1 and MS2 in FIG 1A) to implement a fan-out of two. In a similar manner a set of n lists are maintained in an embodiment of the controller that uses a fan-out of n.

FIG. 1B shows a high-level flowchart of a scheduling method 140, in one embodiment executed by the controller of FIG. 1A. According to this embodiment, a multicast connection request is received in act 141. Then a connection to satisfy the request is set up in act 142 by fanning out into at most two switches in middle stage 130 from its input switch.

In the example illustrated in FIG. 1A, a fan-out of four is possible to satisfy a multicast connection request if input switch is IS2, but only two middle stage switches will be used in accordance with this method. Similarly, although a fan-out of three is possible for a multicast connection request if the input switch is IS1, again only a fan-out of two is used. The specific middle switches that are chosen when selecting a fan-out of two is irrelevant to the method of FIG. 1B so long as at most two middle switches are selected to ensure that the connection request is satisfied, i.e. the destination switches identified by the connection request can be reached from the middle switches that are part of the selected fan-out. In essence, limiting the fan-out from input switch to no more than two middle switches permits the network 100 to be operated in strictly nonblocking manner in accordance with the invention.

After act 142, the control is returned to act 141 so that acts 141 and 142 are executed in a loop for each multicast connection request. According to one embodiment as shown further below it is not necessary to have more than $3*n-1$ middle stage switches in network o100 f the FIG. 1A, where the number of inlet links IL1-IL3 equals the number of outlet links OL1-OL3, both represented by the variable n for the network to be a strictly nonblocking symmetrical switching network, when the scheduling method of FIG. 1B is used.

The connection request of the type described above in reference to method 140 of FIG. 1B can be unicast connection request, a multicast connection request or a broadcast connection request, depending on the example. In case of a unicast connection request, a

fan-out of one is used, i.e. a single middle stage switch is used to satisfy the request. Moreover, although in the above-described embodiment a limit of two has been placed on the fan-out into the middle stage switches, the limit can be greater depending on the number of middle stage switches in a network, as discussed below in reference to FIG. 2A (while maintaining the strictly nonblocking nature of operation of the network). Moreover, in method 140 described above in reference to FIG. 1B any arbitrary fan-out may be used between each middle stage switch and the output stage switches, and also any arbitrary fan-out may be used within each output stage switch, to satisfy the connection request. Moreover, although method 140 of FIG. 1B has been illustrated with examples in a sixteen switch network 100 of FIG. 1A, the method 140 can be used with any general network, of the type illustrated in FIGs. 2A and 2B.

Network of FIG. 1A is an example of general symmetrical three-stage network shown in FIG. 2A. The general symmetrical three-stage network can be operated in strictly nonblocking manner if $m \geq 3*n-1$ (and in the example of FIG. 2A, $m = 3*n-1$), wherein has n inlet links for each of r input switches IS1-ISr (for example the links IS11-IS1n to the input switch IS1) and n outlet links for each of r output switches OS1-OSr (for example OS11-OS1n to the output switch OS1). Each of the m switches MS1-MSm are connected to each of the input switches through r first internal links (for example the links FL11-FLr1 connected to the middle switch MS1 from each of the input switch IS1-ISr), and connected to each of the output switches through r second internal links (for example the links SL11-SLr1 connected from the middle switch MS1 to each of the output switch OS1-OSr). In such a general symmetrical network no more than $3*n-1$ middle stage switches MS1-MS(3n-1) are necessary for the network to be strictly nonblocking, when using a scheduling method of the type illustrated in FIG. 1B. Although FIG. 2A shows an equal number of first internal links and second internal links, as is the case for a symmetrical three-stage network, the present invention, however, applies even to non-symmetrical networks of the type illustrated in FIG 2B (described next).

In general, an $(N_1 * N_2)$ asymmetric network of three stages can be operated in strictly nonblocking manner if $m \geq 2*n_1+n_2-1$ (and in the example of FIG. 2B $m = 2*n_1+n_2-1$, wherein network (FIG. 2B) has r_1 $(n_1 * m)$ switches IS1-ISr$_1$ in the